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(54) Title: GENERATION OF HUMAN INSULIN (57) Abstract An improved and efficient process for the production of recombinant human insulin by folding of a proinsulin hybrid polypeptide is provided.		

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GENERATION OF HUMAN INSULIN

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This is a continuation-in-part of U.S. Serial No. 08/175,298, filed December 29, 1993.

Background of the Invention

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Throughout this specification, various publications are referenced by Arabic numerals within parentheses. Full citations for these references may be found at the end of the specification immediately preceding the claims. The disclosures of these publications in their entireties are hereby incorporated by reference into this specification in order to more fully describe the state of the art to which this invention pertains.

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Insulin is a polypeptide hormone essential for the control of glucose metabolism and it is administered daily to patients suffering from diabetes mellitus, a metabolic disorder characterized by an inadequate supply of insulin.

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In vivo, the hormone is first synthesized as a long precursor molecule, subsequently processed to its biologically active form, consisting of an A and a B chain. In more detail, the gene for preproinsulin is transcribed in the beta cells of the endocrine pancreas into an mRNA precursor, which is then spliced to produce mature mRNA. This mRNA is translated into preproinsulin (NH₂-preregion-B chain-C peptide-A chain-COOH), which is sequentially processed into proinsulin and finally into insulin. The first step in the processing is the proteolytic elimination of the preregion, which serves as a hydrophobic signal sequence for the transfer of the nascent chain through the microsomal membranes of the rough endoplasmatic reticulum. In human preproinsulin, the length of the preregion is 24 amino acids.

In proinsulin, the two regions of the polypeptide chain that will become the mature insulin, the B- and A chains, are connected to each other by the C peptide (or C-chain), which comprises at the N and C termini two pairs of basic amino acids. In most C-peptides, these pairs are Arg-Arg and Lys-Arg. The human C peptide, including the two flanking pairs of basic amino acids, contains 35 amino acids. The C peptide connects the two portions of the polypeptide in order to aid in appropriate disulfide bridge formation between the B and A segments. Therefore the role of the C peptide does not depend greatly on its structure. In fact, its replacement by a shorter synthetic bridge still allows proper folding of the proinsulin molecule (1,2).

The proinsulin folds with the concomitant oxidation of two interchain disulfide bonds and of one disulfide bond within the A chain. In the last stage of maturation, proteolytic enzymes cleave at the basic amino acids to release the C peptide and form the mature insulin (3). In human insulin, the A chain is 21 amino acids long while the B chain is 30 amino acids long.

World demand for insulin exceeds several tons annually and there is a severe shortage of supply. Traditionally, insulin was produced from limited animal sources, mainly bovine and porcine pancreatic preparations, which differ from human insulin and may elicit an adverse immune reaction.

Studies carried out during the 1960's demonstrated in vitro production of insulin. Insulin synthesis was achieved by combining the A and B chains in their S-sulfonated forms (4) or by the spontaneous reoxidation of reduced proinsulin (5). The latter method was not practical for large scale insulin production due to very low protein concentration in the oxidation mixture. Insulin could subsequently be recovered

following treatment with trypsin and carboxypeptidase B (6).

5 Semi-synthetic and biosynthetic (recombinant) human insulin
have recently become available. Semi-synthetic human
insulin is produced from porcine insulin by the trypsin
catalyzed exchange of alanine with threonine at position 30
of the B chain (the only difference between porcine and
human insulin). The recombinant human insulin produced
either in E. coli or yeast will eventually replace all other
10 routes of manufacture.

Biosynthetic recombinant human insulin is currently
manufactured by two routes: either by producing the A and B
chains separately in E. coli and subsequently combining them
15 (7,8), or by enzymatic conversion of pro-insulin like
polypeptides expressed in either E. coli (1,8) or yeast
(2,9).

20 In most cases proinsulin is produced as a hybrid protein
which accumulates as intracellular precipitated protein.
This hybrid is normally purified and cleaved by CNBr in
order to release the proinsulin polypeptide. The latter is
further modified by oxidative sulfitolysis to proinsulin S-
sulfonate. The proinsulin S-sulfonate is then purified and
25 folded, under reducing conditions, to proinsulin (8).
Conversion of the proinsulin to insulin is achieved by the
combined action of trypsin and carboxypeptidase B (6).

30 Patent Publication No. EP 195691 B1, assigned to Novo
Nordisk A/S describes a proinsulin of the formula B-Lys-Arg-
A and the use thereof for the preparation of insulin in
yeast.

35 Patent Publication No. EP 196056 B1, assigned to Chiron
Corp., describes an hSOD-proinsulin protein produced by
yeast. The hSOD-proinsulin protein is subjected to cyanogen
bromide cleavage and sulfitolysis prior to folding.

Hoechst discloses in EPO Publication No. 379162 that 'false recombinants of insulin precursors' (i.e. recombinant insulin products with incorrect or partially incorrect intermolecular disulfide bridges) can be converted to
5 'correct' insulin products without sulfitolysis by reacting the false recombinants with excess mercaptan in an aqueous medium in the presence of an organic redox system. The original sulfitolysis step takes place after the amino acid or peptide radical is cleaved off (chemically or
10 enzymatically) from the fusion polypeptide (which takes place after lysis of the host cell) since then the six cysteines of the insulin precursor are converted into their S-sulfonates. In a subsequent renaturing step, natural proinsulin is produced from this proinsulin S-sulfonate by
15 formation of the three correct disulfide bridges. During this renaturing step, the so-called 'false recombinants' are produced.

Hoechst further discloses, in PCT International Publication
20 No. WO 91/03550, a process for the preparation of fusion proteins containing a desired protein (e.g. proinsulin) and a "ballast constituent". Sulfitolysis is carried out before folding while the "ballast constituent" is cleaved off concomitantly with the C-chain of the proinsulin, after
25 folding.

In addition, Hoechst describes in EP 347781 B1, a "mini-proinsulin" (B-Arg-A) and the use thereof for the preparation of mono-Arg insulin and insulin. They further
30 describe fusion proteins which comprise B-Arg-A and a "ballast constituent". The "ballast constituent" is cleaved off by cyanogen bromide and sulfitolysis is carried out before folding of the polypeptide.

35 The subject invention discloses recombinant human insulin production by an improved and efficient process. Recombinant proinsulin hybrid polypeptides comprising a

leader sequence are synthesized in E.coli. After partial purification, they are folded with the leader peptide still attached under conditions which permit correct folding. Biologically active human insulin is then produced by
5 combined treatment with trypsin and carboxypeptidase B in which these enzymes cleave off the leader peptide and the C-chain concomitantly. The purified human insulin thus produced is identical to naturally occurring human insulin.

10 The hazardous and cumbersome procedures involved in CNBr cleavage of hybrid polypeptides and sulfitolysis used to protect the abundant SH groups are excluded from this novel process since the entire proinsulin hybrid polypeptide can fold efficiently into its native structure even in the
15 presence of the leader peptide and the unprotected cysteine residues. The active recombinant human insulin is released by enzymatic cleavage and is thereafter purified.

Brief Description of the Figures

5 The restriction maps for the three plasmids shown in Figures 3-5 do not identify all restriction sites present on these plasmids. However, those restriction sites necessary for a complete understanding of the invention, are shown.

10 **Figure 1:** Human insulin generation by enzymatic cleavage of the folded, disulfide bonded proinsulin hybrid polypeptide produced by expression of plasmid pBAST-R. Only part of the SOD leader sequence is indicated.

15 **Figure 2:** Human insulin generation by enzymatic cleavage of the folded, disulfide bonded proinsulin hybrid polypeptide produced by expression of plasmid pDBAST-LAT or plasmid p λ BAST-LAT. Only part of the SOD leader sequence is indicated.

20 **Figure 3:** Structure of plasmid pBAST-R, an expression plasmid encoding an SOD-proinsulin hybrid polypeptide deposited with the ATCC under ATCC Accession No. 69362.

25 **Figure 4:** Structure of pDBAST-LAT, an expression plasmid encoding an SOD-proinsulin hybrid polypeptide deposited with the ATCC under ATCC Accession No. 69361.

30 **Figure 5:** Structure of p λ BAST-LAT, an expression plasmid encoding an SOD-proinsulin hybrid polypeptide deposited with the ATCC under ATCC Accession No. 69363.

Figure 6: Amino acid and corresponding DNA nucleotide sequence of the SOD-proinsulin hybrid polypeptide expressed by plasmid pBAST-R.

35 **Figure 7:** Amino acid and corresponding DNA nucleotide sequence of the SOD-proinsulin hybrid polypeptide expressed by plasmids pDBAST-LAT and p λ BAST-LAT.

Figure 8: Human insulin production, from the proinsulin hybrid polypeptide expressed by plasmid pBAST-R, as a function of the pH of the folding mixture.

5 Folding of the proinsulin hybrid polypeptide (produced as described in Example 2) was performed at various pH's as indicated in 100mM glycine buffer at 4°C for about 16 hours with either 1 mg/ml or 0.5 mg/ml of the hybrid polypeptide. The folded material was treated with trypsin (1:500 w/w)
10 (Sigma) and carboxypeptidase B (CPB, Sigma, 1:200 w/w) for 30 minutes at 37° at pH 9 and assayed for immunoreactive (IR) insulin by radioimmunoassay utilizing ¹²⁵I-insulin (Amersham) and human recombinant insulin (Calbiochem) as standard.

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Figure 9: Human insulin production from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT

20 The proinsulin hybrid polypeptide (produced as described in Example 2) was dissolved in 8M urea, 5mM HCl at a concentration of about 30 mg/ml and diluted to 1 mg/ml in 100mM glycine-NaOH, pH 11.0. Folding was carried out at 22°C (room temperature) for 20 hours. The solution was then
25 adjusted to pH 8.8 with HCl. Carboxypeptidase B (1:1000 w/w, Sigma) and trypsin (1:2000 w/w, Sigma) were added and the reaction mixture was incubated at 37°C for 60 minutes. Digestion mixtures were acidified to pH 3 before being diluted with 10 mM HCl. 150 µl aliquots were analyzed by
30 Reverse Phase-High Pressure Liquid Chromatography (RP-HPLC) on a 250x4 mm, 5µ Lichrosphere 100 RP-8 column (Merck) which was equilibrated with 50 mM tetraethylammonium phosphate, 162mM NaClO₄, pH 3, containing 31.5% (v/v) acetonitrile. The column was developed with a linear gradient of 31.5-
35 40.5% acetonitrile during 75 minutes at a flow rate of 1 ml/minute. Absorbance was monitored at 220 nm.

- A: 5 μ g of standard insulin (Boehringer-Mannheim);
- B: recombinant human insulin produced following enzymatic treatment;
- 5 C: folded SOD-proinsulin hybrid polypeptide.

10 **Figure 10:** Human insulin production from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT as a function of the pH in the folding mixture

The proinsulin hybrid polypeptide (produced as described in Example 2) was diluted to 1 mg/ml in 100mM glycine-NaOH buffer having the indicated pH values and was folded at 22°C for 16 hours. Enzyme treatment and RP-HPLC analysis was carried out as described in Figure 9. The amount of recombinant human insulin produced from the hybrid polypeptide was calculated according to the area of the peak which had the same retention time as standard insulin.

20 **Figure 11:** Human insulin production from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT as a function of the ascorbic acid concentration in the folding mixture

25 Folding of the SOD-proinsulin hybrid polypeptide (produced as described in Example 2) was carried out at 1 mg/ml in 100mM glycine-NaOH at 22°C, pH 11.2 in the presence of the indicated concentrations of ascorbic acid. Samples were treated with trypsin and carboxypeptidase B (as in Figure 9) after 5 and 25 hour folding periods. Recombinant human insulin production was analyzed on RP-HPLC (as in Figure 9).

30 **Figure 12:** Authenticity of human insulin produced from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT

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Folding of the SOD-proinsulin hybrid polypeptide (produced as described in Example 2) was carried out at 1 mg/ml in 100mM glycine-NaOH, pH 11.2 and 1.2mM ascorbic acid at 22°C for 16 hours. Following enzymatic treatment (as in Figure 9), the mixture was chromatographed on a DEAE-Sepharose column equilibrated in 20mM Tris-HCl, pH 8. Recombinant human insulin was eluted with a linear gradient of 0-0.4M NaCl in 20mM Tris-HCl, pH 8. Peak fractions were pooled and acidified with HCl to pH 3. The recombinant human insulin was further purified from insulin-like molecules by RP-HPLC as described for Figure 9. The major peak was collected, desalted on Sephadex G-25 column in 0.25M Acetic acid and lyophilized. Samples (5 µg of recombinant human insulin) were prepared in 10mM HCl and were analyzed by RP-HPLC under the same conditions.

- A: Standard insulin;
- B: HPLC purified recombinant human insulin ;
- C: Combined sample of HPLC purified recombinant human insulin and standard insulin.

Figure 13: Human insulin production from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT as a function of the protein concentration in the folding mixture

SOD-proinsulin hybrid polypeptide (produced as described in Example 2) was folded in 100mM Glycine-NaOH, pH 11.2 at a final protein concentration from 0.5 mg/ml to 10 mg/ml as indicated. Each folding mixture was supplemented with 2.5 moles ascorbic acid per mole SH group. Folding was carried out at 24°C (room temperature) for 16 hours. Enzymatic treatment and RP-HPLC analysis were performed as described for Figure 9.

Figure 14: Human insulin production from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT from crude intracellular precipitate as a function of folding time

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Intracellular precipitate was dissolved in 20mM Glycine - NaOH, 33 μ M EDTA, pH 11.2 at a concentration of about 2.6 A₂₈₀ per ml. The pH was adjusted to 12 with 10N sodium hydroxide. The solution was left stirring for 10 minutes. The pH was titrated to 11.2 with concentrated hydrochloric acid. Activated charcoal (acid washed, Sigma) was added to 0.1% w/v final concentration and the mixture was stirred for 30 minutes. The suspension was centrifuged (20 min., 12000 rpm) at 20°C. The clarified supernatant had an A₂₈₀ of about 2.15. Ascorbic acid was supplemented to 3 mM final concentration. Folding of the proinsulin hybrid polypeptide was carried out as shown, with vigorous stirring at room temperature (22-23°C). At various time points along the experiment (starting from dissolution) 10 ml aliquots were withdrawn, titrated to pH 8.8 and digested with carboxypeptidase B (1:1000 w/w) and trypsin (1:2000 w/w) for 1 hour at 37°C in the presence of 50 μ M ZnCl₂. Digestion was terminated by acidification. Insulin content in each digested sample was determined by RP-HPLC analysis as described in Figure 9. The progress of the folding reaction is manifested by the increase of insulin (after digestion), and the decrease in the level of free thiol groups, the latter being assayed by the Ellman reaction (16).

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Summary of the Invention

5 The subject invention provides a method of producing human insulin which comprises folding a hybrid polypeptide comprising proinsulin under conditions that permit correct disulfide bond formation, subjecting the folded, disulfide bonded hybrid polypeptide to enzymatic cleavage to produce active human insulin, and purifying the active human insulin.

10

The subject invention further provides a polypeptide comprising proinsulin and a leader peptide attached to the N-terminus of the proinsulin, wherein the polypeptide is folded and contains correct disulfide bonds.

15

Detailed Description of the Invention

5 The plasmids pBAST-R, pDBAST-LAT and pλBAST-LAT were deposited in E. coli pursuant to, and in satisfaction of, the requirements of the Budapest Treaty on the International Recognition of the Deposit of Microorganisms for the Purposes of Patent Procedure with the American Type Culture Collection (ATCC), 12301 Parklawn Drive, Rockville, Maryland 20852 under ATCC Accession Nos. 69362, 69361 and 69363
10 respectively on July 26, 1993.

As used herein, a hybrid polypeptide comprises a leader peptide covalently attached to a desired polypeptide. The hybrid polypeptide of the subject invention comprises
15 proinsulin, and preferably comprises SOD as the leader peptide.

As used herein, folding comprises folding of a hybrid polypeptide comprising proinsulin without CNBr cleavage
20 before folding and without sulfitolysis before folding to protect SH groups, wherein the folding permits correct disulfide bond formation in the hybrid polypeptide.

As used herein, correct disulfide bond formation of the hybrid polypeptide comprises the formation of three
25 disulfide bonds between Cys^{B7}-Cys^{A7}, Cys^{B19}-Cys^{A20}, and Cys^{A6}-Cys^{A11} of insulin (Cys residues are numbered according to their numbering in mature insulin).

30 As used herein, proinsulin comprises a polypeptide comprising, from N-terminal to C-terminal order, the B, C and A chains of insulin.

As used herein, the C-chain peptide of insulin comprises the
35 naturally-occurring C-peptide and any other oligopeptide, dipeptide or single amino acid which can be cleaved off by trypsin and carboxypeptidase B.

As used herein, a leader peptide comprises any peptide or polypeptide covalently attached to the B chain of insulin which permits folding and disulfide bond formation and which can be cleaved off by means of trypsin. The leader peptide
5 is preferably SOD.

As used herein, SOD comprises any substantial part of the amino acid sequence of CuZnSOD or MnSOD and said part does not necessarily have the biological activity of SOD nor does
10 it necessarily have the identical amino acid sequence of such a part compared to the amino acid sequence of naturally-occurring SOD. The DNA encoding the SOD may be mutated by methods known to those skilled in the art, e.g. Bauer et al. (1985), Gene 37: 73-81.

15 The leader peptide may comprise, instead of SOD, any other peptide, polypeptide or protein or any substantial part of the amino acid sequence of such a peptide, polypeptide or protein wherein said part does not necessarily have the biological activity of said peptide, polypeptide or protein
20 nor does it necessarily have the identical amino acid sequence of such a part compared to the amino acid sequence of the naturally-occurring peptide, polypeptide or protein; however the leader peptide must permit folding and correct
25 disulfide bond formation of the hybrid polypeptide.

As used herein, insulin may comprise a homolog of naturally occurring insulin.

30 As used herein, proinsulin may comprise a homolog of naturally occurring proinsulin.

As used herein, the term "homolog" relating to the insulin polypeptide produced by the methods of the subject
35 invention, is a polypeptide which has substantially the same amino acid sequence and substantially the same biological activity as insulin. Thus, a homolog may differ from the

insulin polypeptide produced by the methods of the invention by the addition, deletion, or substitution of one or more non-essential amino acid residues, provided that the resulting polypeptide retains the biological activity of insulin. Persons skilled in the art can readily determine which amino acids residues may be added, deleted, or substituted (including with which amino acids such substitutions may be made) using established well known procedures, including, for example, conventional methods for the design and manufacture of DNA sequences coding for bacterial expression of polypeptide homologs of the subject polypeptide, the modification of cDNA and genomic sequences by site-directed mutagenesis techniques, the construction of recombinant proteins and expression vectors, the bacterial expression of the polypeptides, and the measurement of the biochemical activity of the polypeptides using conventional biochemical assays.

The above definition of homologs of insulin applies equally to homologs of proinsulin.

Examples of homologs of insulin produced by the methods of the subject invention are deletion homologs containing less than all the residues of naturally-occurring insulin, substitution homologs wherein one or more residues specified are replaced by other residues, and addition homologs wherein one or more amino acids residues are added to a terminal or medial portion of the insulin polypeptide, all of which share the biological activity of insulin.

Examples of homologs are the insulin analogs disclosed in EPO Patent Application EP 384472 and also the insulin analog "Humalog" of Eli Lilly as disclosed in "Eli Lilly and Company Report to Shareholders 1992".

Substantially the same amino acid sequence is herein defined as encompassing substitutions and/or deletions and/or

additions of amino acids in the amino acid sequence and may encompass up to ten (10) residues in accordance with the homologous or equivalence groups as described by e.g. Albert L. Lehninger, Biochemistry, second edition, Worth Publishers Inc. (1975), Chapter 4; Creighton, protein Structure, a Practical Approach, IRL Press at Oxford University Press, Oxford, England (1989); and Margaret O. Dayhoff, Atlas of Protein Sequence and Structure, Volume 5, The National Biomedical Research Foundation (1972), Chapter 9. Such substitutions are known to those skilled in the art.

The DNA encoding the insulin polypeptide may be mutated by methods known to those skilled in the art, e.g. Bauer et al. (1985), Gene 37: 73-81. The mutated sequence may be inserted into suitable expression vectors as described herein, which are introduced into cells which are then treated so that the mutated DNA directs expression of the polypeptide homolog.

The plasmids of the subject invention comprising a sequence encoding a hybrid polypeptide comprising proinsulin may be adapted for expression in bacteria, yeast, fungi or mammalian cells such as CHO, chicken embryo, fibroblast or other known cell lines which additionally comprise the regulatory elements necessary for expression of the cloned gene in the bacteria, yeast, fungi or mammalian cells, so located relative to the nucleic acid encoding the hybrid polypeptide, in order to permit expression thereof. Regulatory elements required for expression include promotor sequences to bind RNA polymerase and a ribosomal binding site for ribosome binding.

The plasmids of the subject invention express a hybrid polypeptide comprising proinsulin.

Those skilled in the art will understand that the plasmids deposited in connection with this application may be readily

altered by known techniques (e.g. by site-directed mutagenesis or by insertion of linkers) to encode expression of homologous polypeptides. Such techniques are described for example in Sambrook, J., Fritsch, E.F. and Maniatis, T. 5 (1989) Molecular Cloning: A Laboratory Manual, 2nd edition, Cold Spring Harbor Laboratory Press.

The suitable regulatory elements are positioned within the plasmid relative to the DNA encoding the hybrid polypeptide 10 comprising proinsulin, so as to effect expression of the hybrid polypeptide in a suitable host cell. In preferred embodiments of the invention, the regulatory elements are positioned close to and upstream of the DNA encoding the hybrid polypeptide.

15 Various ribosomal binding sites (RBS's), for rendering mRNA transcribed from DNA encoding a hybrid polypeptide comprising proinsulin capable of binding to ribosomes within the host cell, are also included in the subject invention, 20 such as the deo RBS.

The plasmids of the invention also contain an ATG initiation codon. The DNA encoding the hybrid polypeptide comprising proinsulin is in phase with the ATG initiation codon. 25

The plasmids of the invention also include a DNA sequence comprising an origin of replication from a bacterial plasmid capable of autonomous replication in the host cell. Suitable origins of replication may be obtained from 30 numerous sources, such as from plasmid pBR322 (ATCC Accession No. 37017).

The plasmids of the subject invention also include a DNA sequence which contains a gene associated with a selectable 35 or identifiable phenotypic trait which is manifested when the plasmid is present in the host cell such as a drug

resistance gene, e.g. resistance to ampicillin, chloramphenicol or tetracycline.

5 Examples of vectors that may be used to express the nucleic acid encoding the hybrid polypeptides (comprising proinsulin) are viruses such as bacterial viruses, e.g., bacteriophages (such as phage lambda), cosmids, plasmids and other vectors. Genes encoding hybrid polypeptides comprising proinsulin are inserted into appropriate vectors by methods
10 well known in the art. For example, using conventional restriction endonuclease enzyme sites, inserts and vector DNA can both be cleaved to create complementary ends which base pair with each other and are then ligated together with a DNA ligase. Alternatively, synthetic linkers harboring
15 base sequences complementary to a restriction site in the vector DNA can be ligated to the insert DNA, which is then digested with the restriction enzyme which cuts at that site. Other means are also available.

20 Preferred bacterial host cells are E. coli cells. Examples of suitable E. coli cells are strains S ϕ 733 (cytRstrA) or 4300, but other E. coli strains and other bacteria can also be used as hosts for the plasmids.

25 The bacteria used as hosts may be any strain including auxotrophic (such as A1645), prototrophic (such as A4255), and lytic strains; F⁺ and F⁻ strains; strains harboring the cI857 repressor sequence of the λ prophage (such as A1645 and A4255) and strains devoid of the deo repressors and/or
30 the deo gene (see European Patent Application Publication No. 0303972, published February 22, 1989). E. coli strain S ϕ 733 and E. coli strain 4300 have been deposited under ATCC Accession Nos. 69361 and 69363 respectively.

35 All the E. coli host strains described above can be "cured" of the plasmids they harbor by methods well known in the

art, e.g. the ethidium bromide method described by R.P. Novick in Bacteriol. Review 33, 210 (1969).

5 The subject invention provides a method of producing insulin which comprises folding a hybrid polypeptide comprising proinsulin under conditions that permit correct disulfide bond formation, subjecting the folded, disulfide bonded hybrid polypeptide to enzymatic cleavage to produce insulin, and purifying the insulin. The insulin has the activity and
10 properties of commercially available human insulin.

In a preferred embodiment, the folding comprises incubating the hybrid polypeptide at about 4-37°C for a period of about 1-30 hours at a pH of about 8.5-12.0.

15 In another preferred embodiment, the folding comprises incubating the hybrid polypeptide at about 4-37°C for a period of about 1-30 hours at a pH of about 8.5-12.0 in the presence of ascorbic acid.

20 In an especially preferred embodiment the pH during folding is 11.0-11.25.

25 In another especially preferred embodiment the concentration of ascorbic acid is about 2 moles per mole SH group present in the folding mixture.

In yet another embodiment the incubation period is about 5 hours.

30 In another embodiment the subjecting comprises adjusting the pH to about 8.8-9.0 and cleaving the hybrid polypeptide with trypsin and carboxypeptidase B at 16-37°C for about 30 minutes to 16 hours.

35 In another embodiment, the purifying comprises DEAE-Sephacrose chromatography and RP-HPLC.

In yet another embodiment, the purifying further comprises ultrafiltration and CM-Sepharose chromatography.

5 In an especially preferred embodiment, the purifying further comprises DEAE-Sepharose chromatography and Phenyl-Sepharose chromatography.

10 In an especially preferred embodiment, the hybrid polypeptide is expressed by plasmid pDBAST-LAT deposited under ATCC Accession No. 69361.

15 In another preferred embodiment the hybrid polypeptide is expressed by plasmid pABAST-LAT deposited under ATCC Accession No. 69363.

In another embodiment the hybrid polypeptide is expressed by plasmid pBAST-R deposited under ATCC Accession No. 69362.

20 In a preferred embodiment the hybrid polypeptide is obtained by treating a bacterial cell containing DNA encoding the hybrid polypeptide, so that the DNA directs expression thereof and recovering the hybrid polypeptide from the cell.

25 It is envisaged that the treating comprises fermentation in the presence of glucose, glycerol or galactose.

30 It is further envisaged that the recovery of the hybrid polypeptide from the cell comprises disrupting the cell wall of the bacterial cell or fragments thereof to produce a lysate, isolating intracellular precipitate from the lysate by centrifugation, solubilizing the precipitate and optionally purifying the hybrid polypeptide by chromatography or ultrafiltration.

35 The subject invention further provides a polypeptide comprising proinsulin and a leader peptide attached to the

N-terminus of the proinsulin, wherein the polypeptide is folded and contains correct disulfide bonds.

5 In a preferred embodiment the leader peptide is derived from the N-terminus of CuZnSOD.

10 In an especially preferred embodiment the leader peptide comprises 62 amino acids, being preceded by the amino acid Met and followed by an Arg residue.

In a preferred embodiment the proinsulin comprises the insulin B-chain linked to the insulin A chain by a single Arg residue.

15 In another embodiment, the proinsulin comprises the insulin B-chain linked to the insulin A chain by the dipeptide Lys-Arg.

20 The above two proinsulin molecules have to be produced as hybrid proteins, otherwise expression levels are extremely low and not of commercial significance.

25 In all preferred embodiments the cysteine residues of the leader peptide have been replaced by serine residues.

Examples

5 The Examples which follow are set forth to aid in
understanding the invention but are not intended to, and
should not be construed to, limit its scope in any way. The
Examples do not include detailed descriptions for
conventional methods employed in the construction of
vectors, the insertion of genes encoding polypeptides into
such vectors or the introduction of the resulting plasmids
10 into hosts. The Examples also do not include detailed
description for conventional methods employed for assaying
the polypeptides produced by such host vector systems. Such
methods are well known to those of ordinary skill in the art
and are described in numerous publications including by way
15 of example the following:

Sambrook, J., Fritsch, E.F. and Maniatis, T. (1989)
Molecular Cloning: A Laboratory Manual, 2nd edition, Cold
Spring Harbor Laboratory Press.

20

Example 1.Construction of production plasmids pBAST-R, pDBAST-LAT and p λ BAST-LAT expressing SOD-proinsulin hybrid polypeptides

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Bacterial expression vectors, which overproduce hybrid proteins in *E. coli*, under the control of either the deo P_1P_2 or λP_L promoter, were constructed. Proinsulin was produced as a hybrid protein since it was found that
10 bacteria harboring an expression vector encoding Insulin B-chain-Lys-Arg-Insulin A-chain produced no detectable polypeptide. The hybrid proteins comprise a leader peptide, 62 amino acids long, derived from the N-terminus of CuZnSOD (11), preceded at the N-terminus by a Met residue and
15 followed at the C-terminus by an Arg residue linking it to insulin B-chain. The insulin B-chain is linked to insulin A-chain by a short C-chain peptide consisting of Lys-Arg or Arg. The two cysteines originally present in the SOD portion were replaced by serine residues.

20

A. Plasmid pBAST-R

A series of plasmids was constructed culminating in pBAST-R, which upon transformation of the proper *E. coli* host cells
25 was capable of directing efficient expression of a proinsulin hybrid polypeptide useful for human insulin production.

The structure of plasmid pBAST-R, encoding SOD-Insulin B
30 chain-Lys-Arg-Insulin A chain hybrid polypeptide is shown in Figure 3; the DNA sequence and corresponding amino acid sequence of the hybrid polypeptide are shown in Figure 6 .

Plasmid pBAST-R is about 4380 bp long and comprises the
35 following elements (in a counterclockwise direction):

1. A DNA fragment, 1521 bp long, spanning AatII-MscI sites on pBR322 which includes the tetracycline resistance gene.
- 5 2. A DNA fragment, 1497 bp long, spanning ScaI-HaeII sites on pBR322 which includes a truncated ampicillin resistance gene and the origin of DNA replication.
- 10 3. A DNA fragment, 930 bp long, spanning AvaII-NdeI sites on E. coli DNA which includes the deo P₁P₂ promoters and ribosomal binding site (RBS) (13).
- 15 4. A DNA fragment, 188 bp long, spanning NdeI-PpuMI sites of human CuZnSOD cDNA. The cysteines at positions 6 and 57 of mature SOD were substituted with serine residues by oligonucleotide site-directed mutagenesis (12).
- 20 5. A synthetic DNA fragment, 172 bp long, with PpuMI and BamHI ends. This region encodes Arg-insulin B chain-Lys-Arg-insulin A chain.
- 25 6. A synthetic 36 bp multiple cloning site polylinker with BamHI and HindIII ends.
- 30 7. A synthetic 44 bp oligonucleotide containing the TrpA transcription terminator with HindIII and AatII ends (10).
- 35 Plasmid pBAST-R, which confers tetracycline resistance and which encodes the SOD-Insulin B chain-Lys-Arg-Insulin A chain hybrid polypeptide, was introduced into E. coli strain SØ733 (cytRstrA) and deposited in the ATCC under ATCC Accession Number 69362 on July 26, 1993.

B. Plasmid pDBAST-LAT

Another series of plasmids was constructed culminating in plasmid pDBAST-LAT, which upon transformation of the proper E. coli host cells was capable of directing efficient high level expression of a proinsulin hybrid polypeptide useful for human insulin production.

The structure of plasmid pDBAST-LAT, encoding SOD-Insulin B chain-Arg-Insulin A chain hybrid polypeptide is shown in Figure 4; the DNA sequence and corresponding amino acid sequence of the hybrid polypeptide are shown in Figure 7. Plasmid pDBAST-LAT is about 4377 bp long and comprises the following elements (in a counterclockwise direction):

1. A DNA fragment, 1521 bp long, spanning AatII-MscI sites on pBR322 which includes the tetracycline resistance gene.
2. A DNA fragment, 1497 bp long, spanning ScaI-HaeII sites on pBR322 which includes a truncated ampicillin resistance gene and the origin of DNA replication.
3. A DNA fragment, 930 bp long, spanning AvaII-NdeI sites on E. coli DNA which includes the deo P₁P₂ promoters and RBS (13).
4. A DNA fragment, 188 bp long, spanning NdeI-PpuMI sites of human CuZnSOD cDNA. The cysteines at positions 6 and 57 of mature SOD were substituted with serine residues and the GC content of this fragment was reduced to 38% by oligonucleotide site-directed mutagenesis (12).
5. A synthetic DNA fragment, 169 bp long, with PpuMI and BamHI ends. This region encodes Arg-insulin B chain-Arg-insulin A chain.

6. A synthetic 36 bp multiple cloning site polylinker with BamHI and HindIII ends.
7. A synthetic 44 bp oligonucleotide containing the TrpA transcription terminator with HindIII and AatII ends (10).

Plasmid pDBAST-LAT, which confers tetracycline resistance and which encodes the SOD-Insulin B chain-Arg-Insulin A chain hybrid polypeptide, was introduced into E. coli strain SØ733 (cytRstrA) and deposited in the ATCC under ATCC Accession Number 69361 on July 26, 1993.

C. Plasmid pλBAST-LAT

Another series of plasmids was constructed culminating in plasmid pλBAST-LAT, which upon transformation of genetically engineered E. coli host cells (harboring the cI857 repressor) was capable of directing efficient expression of a proinsulin hybrid polypeptide useful for human insulin production.

The structure of plasmid pλBAST-LAT, encoding SOD-Insulin B chain-Arg-Insulin A chain hybrid polypeptide is shown in Figure 5. The DNA sequence and corresponding amino acid sequence of the hybrid polypeptide are shown in Figure 7.

Plasmid pλBAST-LAT is about 3777 bp long and comprises the following elements (in a counterclockwise direction):

1. A DNA fragment, 1521 bp long, spanning AatII-MscI sites on pBR322 which includes the tetracycline resistance gene.
2. A DNA fragment, 1497 bp long, spanning ScaI-HaeII sites on pBR322 which includes a truncated ampicillin resistance gene and the origin of DNA replication.

- 26 -

3. A DNA fragment, 330 bp long, spanning BamHI-EcoRI sites on plasmid pSOD α 13 (14) which includes the λ P_L promoter and an AvrII-NdeI 30 base pair long deo ribosomal binding site.
- 5
4. A DNA fragment, 188 bp long, spanning NdeI-PpuMI sites of human CuZnSOD cDNA. The cysteines at positions 6 and 57 of mature SOD were substituted with serine residues and the GC content of this fragment was
- 10 reduced to 38% by oligonucleotide site-directed mutagenesis (12).
5. A synthetic DNA fragment, 169 bp long, with PpuMI and BamHI ends. This region encodes Arg-insulin B chain-
- 15 Arg-insulin A chain.
6. A synthetic 36 bp multiple cloning site polylinker with BamHI and HindIII ends.
7. A synthetic 44 bp oligonucleotide containing the TrpA transcription terminator with HindIII and AatII ends
- 20 (10).

25 Plasmid pABAST-LAT, which confers tetracycline resistance and which encodes the SOD-Insulin B chain-Arg-Insulin A chain hybrid polypeptide under the control of the λ P_L promoter, was introduced into E. coli strain 4300 (F-, bio, cI⁸⁵⁷) and deposited in the ATCC under ATCC Accession No. 69363 on July 26, 1993.

30

Bacterial cells were propagated at 30°C. Production of the hybrid polypeptide was induced upon temperature shift to 42°C.

Example 2.Fermentation, growth conditions and purification of SOD-proinsulin hybrid polypeptides

5

I. Stock Cultures

Stock culture of E. coli strain S ϕ 733 harboring plasmid pDBAST-LAT (or pBAST-R) was grown on casein medium (20gr/L casein hydrolysate, 10gr/l yeast extract and 5gr/L NaCl) supplemented with tetracycline (10mg/L). The cultures were then diluted two-fold with freezing medium and stored at -80°C.

15 Freezing medium:

	K ₂ HPO ₄	6.3 gr
	KH ₂ PO ₄	1.8 gr
	Na Citrate	0.45 gr
	MgSO ₄ .7H ₂ O	0.09 gr
20	(NH ₄) ₂ SO ₄	0.9 gr
	Glycerol	44 gr
	Per 500 ml	

II. Inoculum

25

The inoculum was propagated in production medium (see below). Sterile medium in a shake flask was inoculated from stock culture and incubated 15 hours on a shaker at 37°C and approximately 200 r.p.m. If needed, subsequent stages in inoculum propagation were carried out in stirred aerated fermenters. Sterile medium was inoculated with 2-10% flask culture, and incubated 15 hours at 37°C, pH 7 \pm 0.5 with agitation and aeration to maintain the dissolved oxygen level above 20% air saturation.

35

III. Production

Production medium:

	K_2HPO_4	8 gr/L
5	KH_2PO_4	2 gr/L
	Na citrate	2 gr/L
	NH_4Cl	3 gr/L
	K_2SO_4	0.6 gr/L
	$FeSO_4 \cdot 7H_2O$	0.04 gr/L
10	$MgSO_4 \cdot 7H_2O$	0.4 gr/L
	$CaCl_2 \cdot 2H_2O$	0.02 gr/L
	Trace elements	
	solution	3 ml/L
	Tetracycline	0.01 gr/L
15	Glucose	2 gr/L
	Glycerol	1 ml/L

Trace elements solution:

	$MnSO_4 \cdot H_2O$	1 gr/L
20	$ZnSO_4 \cdot 7H_2O$	2.78 gr/L
	$CoCl_2 \cdot 7H_2O$	2 gr/L
	$Na_2MoO_4 \cdot 2H_2O$	2 gr/L
	$CaCl_2 \cdot 2H_2O$	3 gr/L
	$CuSO_4 \cdot 5H_2O$	1.85 gr/L
25	H_3BO_3	0.5 gr/L
	HCl (32%)	100 ml/L

The production medium was inoculated with 0.5-10% inoculum culture and incubated at 37°C. Agitation-aeration rates were set to maintain the dissolved oxygen level above 20% air saturation. The pH was maintained at 7 ± 0.2 with NH_3 .

Sterile solutions of 50% glucose and 30% glycerol were infused to supply energy and carbon sources. Once cell concentration reached an OD_{660} of 25, sterile solutions of 10% glucose and 30% glycerol were infused and growth continued for about 5 hours until cell concentration reached

an approximate OD₆₆₀ of 60. The culture was then chilled and cells were recovered by centrifugation. Fermentation of E. coli in the presence of any one of glucose, glycerol, galactose or a combination thereof as carbon source facilitated the expression of the SOD-proinsulin hybrid polypeptides.

IV. Purification

The SOD-proinsulin hybrid polypeptides expressed by plasmids pBAST-R and pDBAST-LAT accumulated in intracellular precipitate which was isolated by the following procedure: 1 gr (wet weight) of bacterial cake was suspended in 10 ml buffer containing 50mM Tris-HCl, pH 8, 10mM EDTA and was treated with lysozyme (Merck, 2500 u/ml) at 37°C for 2 hours. The mixture was then sonicated and Nonidet-P-40 (Sigma) or Triton X 100 was added to a final concentration of 2% and stirred for 2 hours at room temperature. The precipitate was pelleted by centrifugation and washed with water.

The hybrid polypeptide was purified to near homogeneity by anion exchange chromatography as follows. The precipitate was dissolved in 8M urea, 20mM Tris-HCl, 200mM β-mercaptoethanol, pH 8.2. The solution was clarified by centrifugation and chromatographed on DEAE-Sepharose Fast-Flow column (Pharmacia LKB), pre-equilibrated in 8M Urea, 20mM Tris-HCl, 20mM β-mercaptoethanol, pH 8.2. Flow-through material was collected and the hybrid protein was either precipitated with (NH₄)₂SO₄ at 40% saturation or concentrated by ultrafiltration on 10K membrane followed by diafiltration against 100mM Glycine-HCl, pH 3.1.

Alternatively, the SOD-proinsulin hybrid polypeptide expressed by plasmid pBAST-R was purified to near homogeneity by dissolution in 8M urea, 20mM Dithiothreitol, 50mM NaAcetate, pH 5, and by ultrafiltration through a

series of 100kD and 50kD membranes (Filtron). The hybrid polypeptide was concentrated on a 10kD membrane and precipitated with $(\text{NH}_4)_2\text{SO}_4$ at 40% saturation.

Example 3.Folding and enzymatic cleavage of the SOD-proinsulin hybrid polypeptides

5

Proinsulin hybrid polypeptides, obtained by $(\text{NH}_4)_2\text{SO}_4$ precipitation or by ultrafiltration (Example 2), were dissolved in 8M urea, 5mM HCl and diluted into 100mM glycine buffer, pH 8.5-12.0 at a final concentration of about 1 mg/ml.

10

A. Folding of the SOD-proinsulin hybrid polypeptide expressed by plasmid pBAST-R took place at about 4-37°C for a period of about 1-24 hours in order to permit correct disulfide bond formation.

15

The pH of the solution containing the folded, disulfide bonded hybrid polypeptide was adjusted to about 8.8-9.0 with HCl and the protein was treated with trypsin and carboxypeptidase B at 16-37°C for 30-120 minutes.

20

After considerable experimentation, it was found that the optimal conditions were as follows: The hybrid polypeptide expressed by plasmid pBAST-R was dissolved in 8M urea, 5mM HCl and diluted into 100mM glycine buffer, pH 11.0 (Figure 8) at a final concentration of about 1 mg/ml, after which folding of the hybrid polypeptide took place for 6-16 hours at 25°C, whereafter the folded, disulfide bonded hybrid polypeptide was cleaved with trypsin (1:500 w/w) and carboxypeptidase B (1:200 w/w) at 37°C for 30-60 minutes.

25

30

Insulin generation by enzymatic cleavage of the folded disulfide bonded proinsulin hybrid polypeptide expressed by plasmid pBAST-R is diagrammatically shown in Figure 1.

35

B. Folding of the SOD-proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT took place at about 7-31°C for a period of about 5-30 hours in order to permit correct disulfide bond formation.

5

The pH of the solution containing the folded, disulfide bonded hybrid polypeptide was adjusted to about 8.8-9.0 with HCl and the protein was treated with trypsin and carboxypeptidase B at 22-37°C for 30 minutes to 16 hours.

10

After considerable experimentation, it was found that the optimal conditions were as follows: The hybrid polypeptide expressed by plasmid pBAST-R was dissolved in 8M urea, 5mM HCl and diluted into 100mM glycine buffer, pH 11.0-11.25 (Figure 8) at a final concentration of about 1 mg/ml, after which folding of the hybrid polypeptide took place for 5 hours at 25°C, whereafter the folded, disulfide bonded hybrid polypeptide was cleaved with trypsin (1:15.000 w/w) and carboxypeptidase B (1:10.000 w/w) at 25°C for 16 hours.

15

20

25

Insulin generation by enzymatic cleavage of the folded disulfide bonded proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT is diagrammatically shown in Figure 2.

Examples of specific conditions for both A and B above are detailed in the legends to Figures 8-14.

30

Example 4.Protein analysis and purification of human insulin from the SOD-proinsulin hybrid polypeptide expressed by plasmid pBAST-R

Human insulin generation from the SOD-proinsulin hybrid polypeptide expressed by plasmid pBAST-R was determined by radioimmunoassay and RP-HPLC, utilizing commercial human insulin as standard (Calbiochem). The theoretical yield of recombinant human insulin as calculated according to the amino acid sequence of the proinsulin hybrid polypeptide is 45.6%. It is evident from Figure 8 that optimal folding occurs at pH 11. At this pH value, insulin production amounts to about 80% of the theoretical yield (which corresponds to about 40% of the input hybrid polypeptide). Human insulin produced from the proinsulin hybrid polypeptide expressed by plasmid pBAST-R, was detected by RP-HPLC. A Vydac 218TP54, 250 x 4.6 mm I.D. (Separation Group), 5 μ m, 300 Å pore size column was used at room temperature with a flow rate of 1 ml/min. 0.1% Trifluoroacetic acid (TFA) in H₂O was used as eluant A and 0.08% TFA in acetonitrile as eluant B. The column was washed for 5 minutes in equilibration buffer (25% eluant B) followed by a linear gradient of 25-50% eluant B during 37.5 minutes. Absorbance was monitored at 220 nm or at 280nm. Analysis of the human insulin following the enzymatic digestion of the folded, disulfide bonded hybrid polypeptide using Reverse Phase-High Pressure Liquid Chromatography revealed a major peak with the same retention time as standard human insulin.

Two small scale batches were prepared yielding 26mg and 13mg of human insulin respectively. Human insulin was purified from the enzyme-treated solution (pH 9) by ultrafiltration on either 3K or 5K membranes (Filtron) followed by CM-Sepharose chromatography (citrate buffer, pH 3). Peak

fractions were desalted, lyophilized and subjected to N-terminal sequencing and amino acid analysis. The amino acid composition of both batches of recombinant human insulin was essentially identical to naturally-occurring human insulin (see Table 1, preparation 1). The sequence of 5 amino acids at the amino terminus of the insulin preparations was determined by Edman degradation. It was found to be identical to the NH₂-terminus of both the A and B chain of human insulin, which confirms the authenticity of the in vitro product.

However, the sequencing results indicated the presence of an extra Arg residue at the first position in about 25% of the molecules. This result corresponds to trypsin cleavage between Lys and Arg, inside the linker sequence Lys-Arg, thus leaving an additional Arg residue on the amino terminus of the A-chain.

It was found that specific hydrolysis at the C-terminal of Arg by trypsin can be achieved by performing the reaction at pH 11. At this elevated pH, most of the ϵ -amino groups of Lys are not charged (pK=10.3) thus enabling selective cleavage. Two batches yielding 1 mg and 6.5 mg of purified insulin were obtained by carrying out the trypsin step at pH 11 (see Table 1, preparation 2) followed by carboxypeptidase B digestion at pH 8.5. N-terminal sequencing revealed that the amount of insulin comprising an extra Arg was reduced to about 5%.

TABLE 1

Amino Acid Composition of Recombinant Human Insulin

Amino Acid	Number of residues			
	Theoretical	Standard Insulin	Preparation 1	Preparation 2
Asx	3	3.20	3.38	3.26
Thr	3	2.98	2.83	2.68
Ser	3	2.84	2.53	2.77
Glx	7	7.15	7.73	7.23
Pro	1	1.28	1.13	1.09
Gly	4	4.24	4.39	4.25
Ala	1	1.00	1.28	1.04
Cys	6	5.88	5.11	5.79
Val	4	3.82	4.58	3.88
Ile	2	2.04	1.96	1.96
Leu	6	5.87	6.10	5.99
Tyr	4	3.80	3.80	3.87
Phe	3	3.15	3.56	3.03
His	2	2.04	2.05	2.08
Lys	1	1.01	1.05	1.02
Arg	1	0.96	1.30	1.18

Preparation 1 and 2 show the amino acid composition of recombinant human insulin produced from the proinsulin hybrid polypeptide expressed by plasmid pBAST-R. Trypsin

cleavage was carried out either at pH 9 (preparation 1) or at pH 11 (preparation 2).

5 Amino acid analysis was performed after performic acid oxidation and gas phase hydrolysis of purified insulin preparations.

Example 5.**Peptide analysis of purified human insulin produced from the
SOD-proinsulin hybrid polypeptide expressed by plasmid
pBAST-R**

Purified human insulin produced as described in the above Examples, was subjected to peptide analysis utilizing endoproteinase Glu-C (Sigma), which hydrolyzes peptide bonds at the carboxyl side of glutamyl residues.

In more detail, insulin samples (100 μ g), produced by cleavage of the folded, disulfide bonded proinsulin hybrid polypeptide expressed by plasmid pBAST-R, were digested with 5 μ g Glu-C for 6 hrs at 37°C in 100 μ l of 0.1 M Tris-HCl, pH 7.8. HPLC analysis was performed: samples of commercially available (control) insulin and insulin produced by cleavage of the folded, disulfide bonded proinsulin hybrid polypeptide expressed by plasmid pBAST-R were acidified to a pH of about 3 and were separated by RP-HPLC. A Vydac 218TP54, 250 x 4.6 mm I.D., 5 μ m, 300 Å pore size column was used. The column was equilibrated with 50 mM tetraethylammonium phosphate, 162mM NaClO₄, pH 3, containing 31.5% (v/v) acetonitrile and was developed with a linear gradient of 35-45% acetonitrile during 75 minutes at a flow rate of 1 ml/minute. Absorbance was monitored at 220nm.

All expected peptides were generated in agreement with the control reaction even though a minor shoulder following the peak corresponding to one of the fragments is probably related to des-Thr(B₃₀) insulin-like molecule (15).

Examples 4 and 5 indicate that the recombinant polypeptide expressed by plasmid pBAST-R comprises the sequence of naturally-occurring human insulin. A minor portion of the recombinant protein produced comprised forms such as Arg(Ao), desamido- or des-Thr(B₃₀) insulin-like molecules.

These unwanted by-products can be eliminated by chromatographic procedures such as RP-HPLC as described above.

Example 6.**Protein analysis and purification of human insulin produced from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT**

5 In order to avoid generation of Arg(Ao) insulin by-product (Examples 4 and 5), expression plasmid pBAST-R was modified to comprise DNA coding only for an Arg residue between the
10 A and B chains of the proinsulin hybrid polypeptide as opposed to DNA coding for Lys-Arg between the A and B chains of the proinsulin hybrid polypeptide expressed by plasmid pBAST-R. This resulted in expression plasmids pDBAST-LAT (Example 1B) and p λ BAST-LAT (Example 1C).

15 Efficient production of insulin occurred following folding and enzymatic treatment with trypsin and CPB of the folded, disulfide bonded proinsulin hybrid polypeptide expressed by new expression plasmid pDBAST-LAT. The presence of insulin-like contaminants was low (Figure 9). Folding was optimal
20 at pH 11.25 (Figure 10) and was significantly enhanced in the presence of about 2 moles ascorbic acid per mole SH group in the reaction mixture (Figure 11).

25 The effect of protein concentration on the yield of insulin produced from proinsulin hybrid polypeptide was determined in a series of reactions under otherwise optimal folding conditions. Optimal yields were obtained when protein concentration did not exceed 1.5 mg/ml (Figure 13).

30 The insulin was purified by DEAE-Sephadex chromatography followed by RP-HPLC (as described in Figure 9). As is evident from Figure 12, the recombinant human insulin produced had the same retention time as standard
35 (commercially available) human insulin. The amino acid composition of the purified recombinant human insulin

preparation is identical to standard insulin (see Table 2, recombinant insulin).

5 Note that Table 2 indicates that the insulin produced from
the proinsulin hybrid polypeptide expressed by plasmid
pDBAST-LAT did not have the extra Arg residue attached to
the insulin A chain (Arg(Ao)insulin) as described in Example
4. Thus the preferred plasmid for production of insulin is
10 plasmid pDBAST-LAT and the preferred sequence for the
proinsulin hybrid polypeptide is that shown in Figure 7.

TABLE 2

Amino Acid Composition of Recombinant Human Insulin

5

10

15

20

Amino Acid	Number of residues		
	Theoretical	Standard Insulin	Recombinant insulin
Asx	3	3.20	3.32
Thr	3	2.98	2.73
Ser	3	2.84	2.71
Glx	7	7.15	7.41
Pro	1	1.28	1.02
Gly	4	4.24	4.46
Ala	1	1.00	1.09
Cys	6	5.88	5.28
Val	4	3.82	4.00
Ile	2	2.04	1.91
Leu	6	5.87	6.34
Tyr	4	3.80	3.64
Phe	3	3.15	3.06
His	2	2.04	2.18
Lys	1	1.01	1.02
Arg	1	0.96	1.07

25

The amino acid composition of standard human insulin and recombinant human insulin produced from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT are shown.

Amino acid analysis was performed after performic acid oxidation and gas phase hydrolysis of purified insulin preparations.

Example 7.

5 Human insulin production from the proinsulin hybrid
polypeptide expressed by plasmid pDBAST-LAT from crude
intracellular precipitate

10 An improved method for folding and enzymatic conversion of
the proinsulin hybrid polypeptide to insulin was carried out
by using crude intracellular precipitate, omitting the need
for the initial purification step as described in Example 2,
part IV. Efficient production of insulin occurred following
enzymatic cleavage of the folded, disulfide bonded
proinsulin hybrid polypeptide with trypsin and
carboxypeptidase B (Figure 14 and Table 3). Insulin yields
15 were calculated as the percent of initial protein
concentration (A_{280}) as determined at the precipitate
dissolution step at pH 12 (Figure 14). Folding of SOD-
proinsulin hybrid polypeptide from crude intracellular
precipitate was shown to be optimal at about 4.5 hours from
20 the start of the experiment (Figure 14).

Table 3 summarizes the partial purification of insulin from
the proinsulin hybrid polypeptide expressed by plasmid
pBAST-LAT from crude intracellular precipitate prepared from
25 one liter fermentation culture at an O.D.₆₆₀ of 45.
Dissolution and folding were carried out as described for
Figure 14. At 4.5 hours from dissolution, the folded bulk
solution including the folded, disulfide bonded proinsulin
hybrid polypeptide was titrated to pH 8.8 with concentrated
30 hydrochloric acid. $ZnCl_2$ (to 50 μM final concentration),
carboxypeptidase B (1:4000 w/w) and trypsin (1:6000 w/w)
were added. Digestion was performed for 3 hours at 37°C and
was terminated by addition of phenylmethylsulfonyl fluoride
(PMSF) to 0.5mM final concentration. Analysis by HPLC (as
35 described in Figure 9) indicated an insulin yield of 169 mg.
Insulin was purified by a sequence of anion-exchange and
hydrophobic chromatographic steps. Digested folding mixture

was loaded on DEAE Sepharose Fast Flow (Pharmacia) column pre-equilibrated in 20mM Tris-HCl, 10mM NaCl pH 8 buffer at about 50 A₂₈₀ units per ml resin. Bound material was washed with 20mM Tris-HCl, 100mM NaCl, pH 8 buffer and insulin
5 eluted with 250mM NaCl in the same buffer. Pool fractions containing insulin represented 20% of loaded protein and had a purity of 37.1%. Ammonium sulfate was added to the DEAE elution pool to a concentration of 410 mM and was loaded on Phenyl-Sepharose Fast Flow column pre-equilibrated in 20mM
10 Tris HCl, 540mM Ammonium sulfate at about 12 A₂₈₀ units per ml resin. Bound material was washed with equilibration buffer and insulin eluted with 20mM Tris HCl, 220mM ammonium sulphate, pH 8 buffer. Fractions containing insulin represented 42.3% of loaded protein and had a purity of
15 74.1%. As a result of this partial purification process, 120 mg insulin, identical to standard insulin, was produced which corresponds to an insulin yield of 5.16%. Further purification of insulin may be carried out by use of methods known in the art, e.g. gel filtration, RP-HPLC and
20 crystallization (17).

TABLE 3

Purification of recombinant human insulin, produced from the proinsulin hybrid polypeptide expressed by plasmid pDBAST-LAT, following dissolution of crude intracellular precipitate, folding and enzymatic treatment with trypsin and carboxypeptidase B.

Purification step	A ₂₈₀	minimum amount of insulin by HPLC - in mg	% purity
Precipitate dissolution	232 6	-	-
Charcoal treatment	191 5	-	-
Folding and enzymatic treatment	191 5	169	8.8
DEAE-Sephadex pool	383	142	37.1
Phenyl-Sephadex pool	162	120	74.1

A₂₈₀ represents the total absorbance at 280 nm at each purification step. Insulin presence was determined by HPLC analysis relative to standard insulin as described for Figure 9 and corresponds to the major insulin peak of standard insulin.

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What is claimed is:

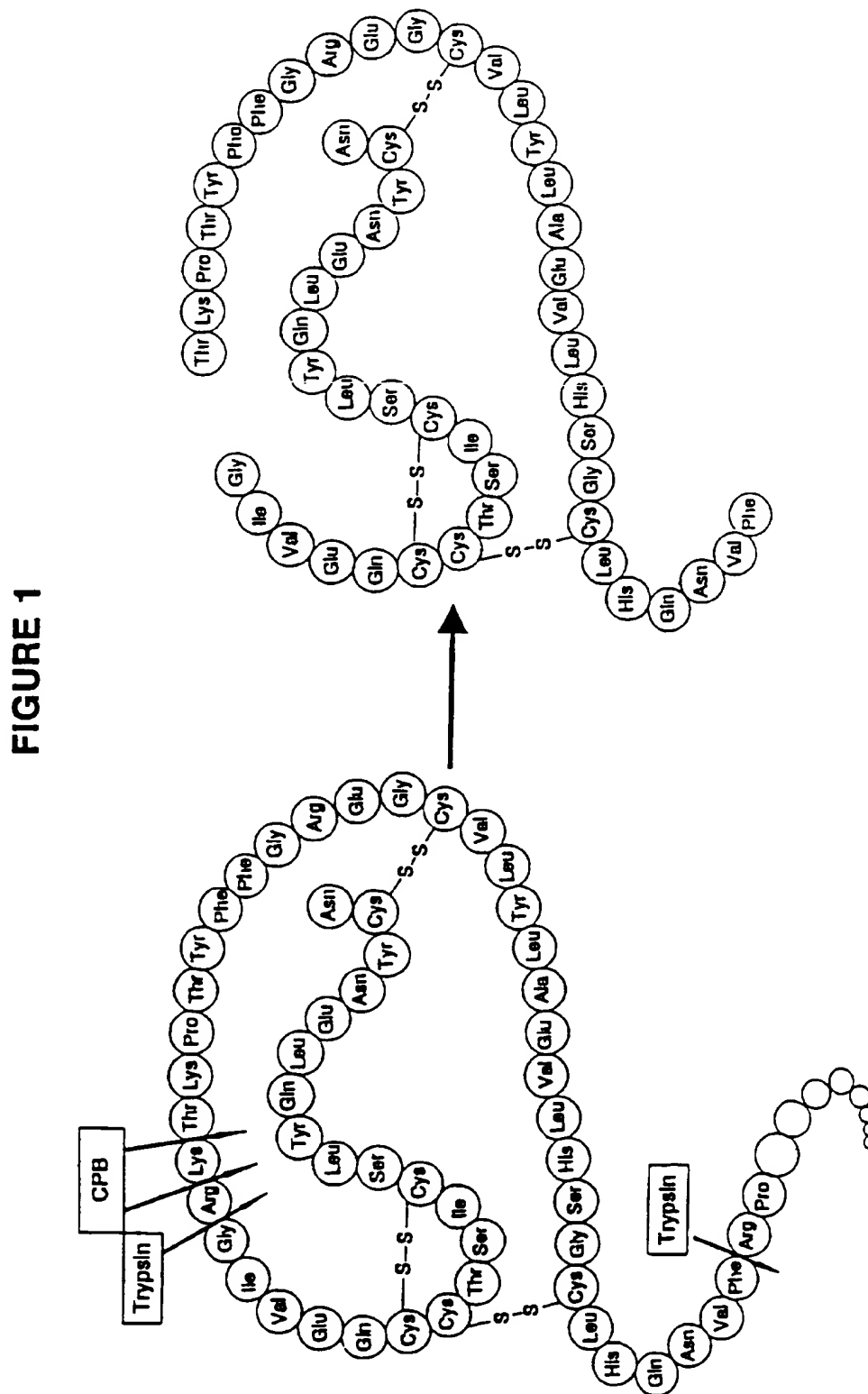
1. A method of producing insulin which comprises:
 - 5 (a) folding a hybrid polypeptide comprising proinsulin under conditions that permit correct disulfide bond formation;
 - (b) 10 subjecting the folded, disulfide bonded hybrid polypeptide to enzymatic cleavage to produce insulin;
 - (c) purifying the insulin.
- 15 2. A method according to claim 1 wherein step (a) further comprises incubating the hybrid polypeptide at about 4-37°C for a period of about 1-30 hours at a pH of about 8.5-12.0.
- 20 3. A method according to claim 2 wherein the incubation takes place in the presence of ascorbic acid.
4. A method according to claim 2 wherein the pH is 11.0-11.25.
- 25 5. A method according to claim 3 wherein the pH is 11.0-11.25.
6. A method according to claim 3 wherein the
30 concentration of ascorbic acid is about 2 moles per mole SH group present in the folding mixture.
7. A method according to claim 2 wherein the incubation period is about 5 hours.
- 35 8. A method according to claim 3 wherein the incubation period is about 5 hours.

9. A method according to claim 1 wherein step (b) further comprises:
- (i) adjusting the pH to about 8.8-9.0; and
- (ii) cleaving the hybrid polypeptide with trypsin and carboxypeptidase B at 16-37°C for 30 minutes to 16 hours.
10. A method according to claim 1 wherein step (c) further comprises purification by means of DEAE-Sepharose chromatography and RP-HPLC.
11. A method according to claim 1 wherein step (c) further comprises purification by means of ultrafiltration and CM-Sepharose chromatography.
12. A method according to claim 1 wherein step (c) further comprises purification by means of DEAE-Sepharose chromatography and Phenyl-Sepharose chromatography.
13. A method according to claim 1 wherein the proinsulin hybrid polypeptide is expressed by plasmid pDBAST-LAT deposited under ATCC Accession No. 69361.
14. A method according to claim 1 wherein the proinsulin hybrid polypeptide is expressed by plasmid pABAST-LAT deposited under ATCC Accession No. 69363.
15. A method according to claim 1 wherein the proinsulin hybrid polypeptide is expressed by plasmid pBAST-R deposited under ATCC Accession No. 69362.

- 5 16. A method according to claim 1 wherein the hybrid polypeptide of step (a) is obtained by treating a bacterial cell containing DNA encoding the hybrid polypeptide, so that the DNA directs expression thereof.
17. A method according to claim 16 wherein the hybrid polypeptide is recovered from the cell.
- 10 18. A method according to claim 16 wherein the treating comprises fermentation in the presence of glucose, glycerol or galactose.
19. A method according to claim 17 wherein the recovery
15 comprises:
- (i) disrupting the cell wall of the bacterial cell or fragments thereof to produce a lysate;
- 20 (ii) isolating intracellular precipitate from the lysate by centrifugation; and
- (iii) solubilizing the precipitate.
- 25 20. A polypeptide comprising proinsulin and a leader peptide attached to the N-terminus of the proinsulin, wherein the polypeptide is folded and contains correct disulfide bonds.
- 30 21. A polypeptide according to claim 20 wherein the leader peptide is derived from the N-terminus of CuZnSOD.
22. A polypeptide according to claim 21 wherein the
35 leader peptide comprises 62 amino acids, being preceded by the amino acid Met and followed by an Arg residue.

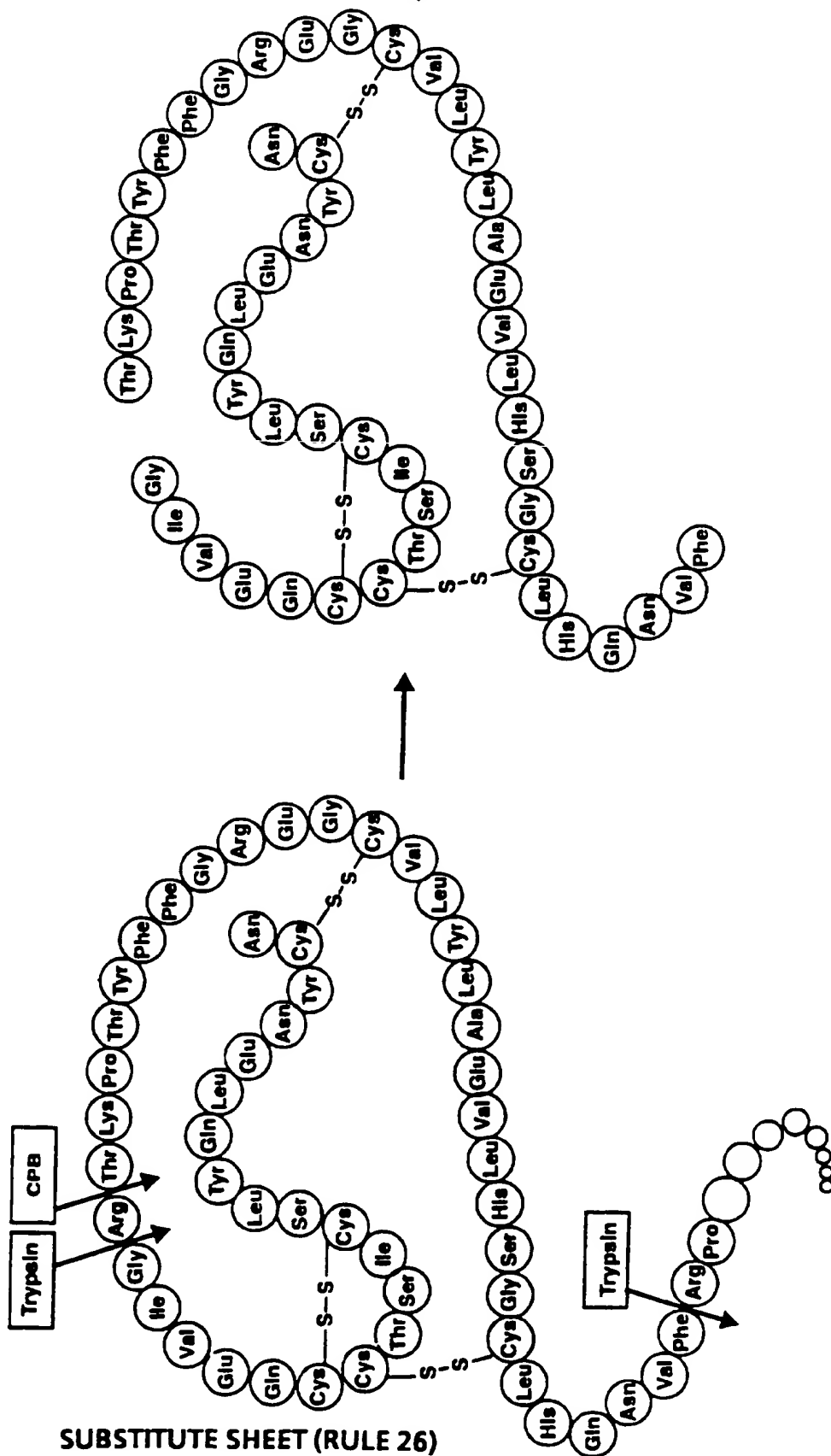
23. A polypeptide according to claim 20 wherein the proinsulin comprises the insulin B-chain covalently attached to the insulin A-chain by a single Arg residue.
- 5
24. A polypeptide according to claim 20 wherein the proinsulin comprises the insulin B-chain covalently attached to the insulin A-chain by the dipeptide Lys-Arg.
- 10
25. A polypeptide according to claim 20 wherein the cysteine residues of the leader peptide have been replaced by serine residues.

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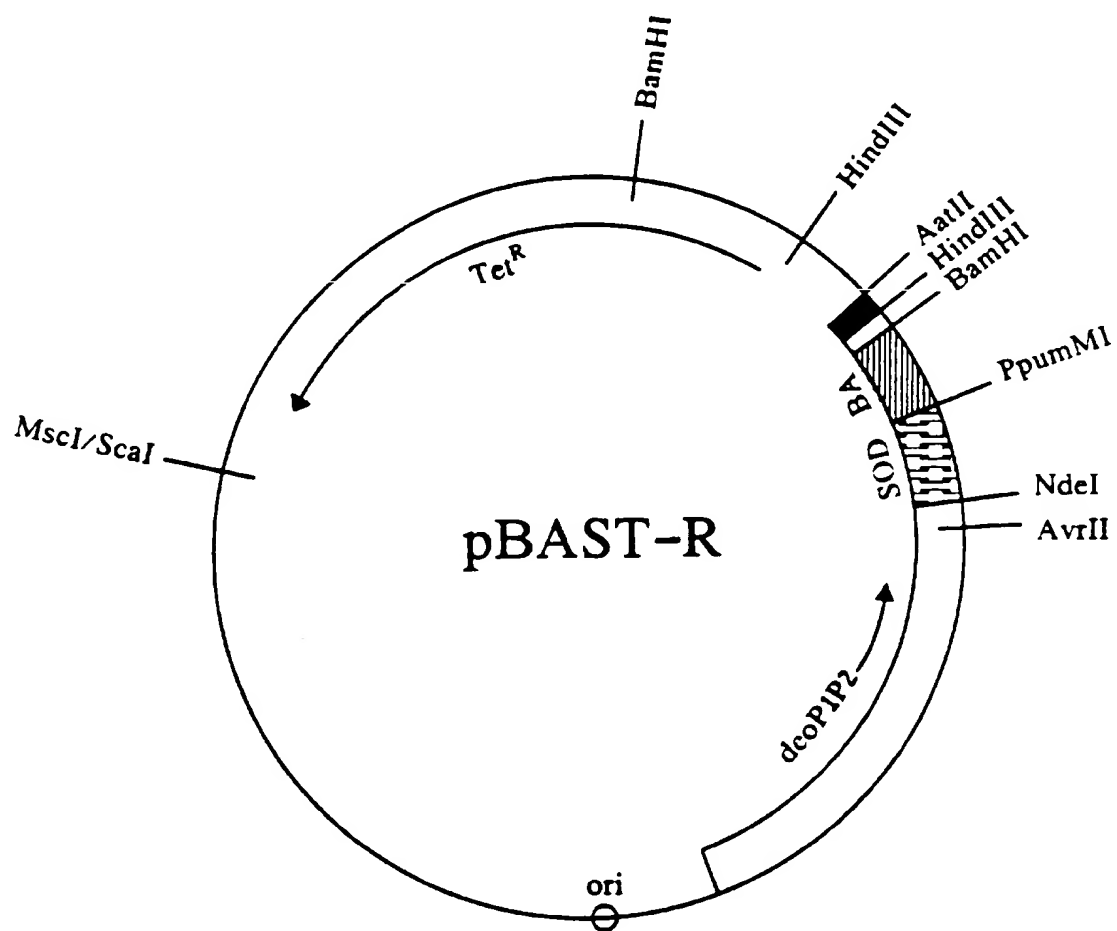
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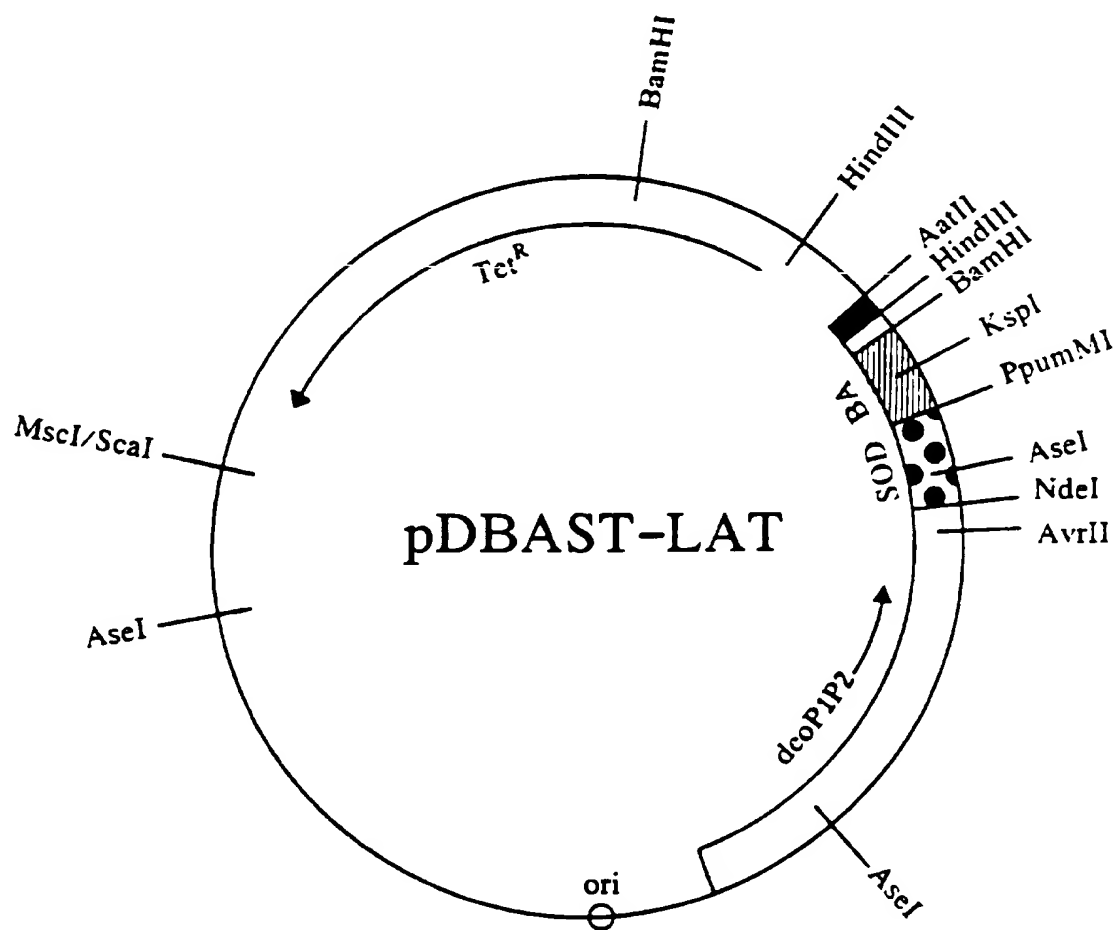
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FIGURE 3



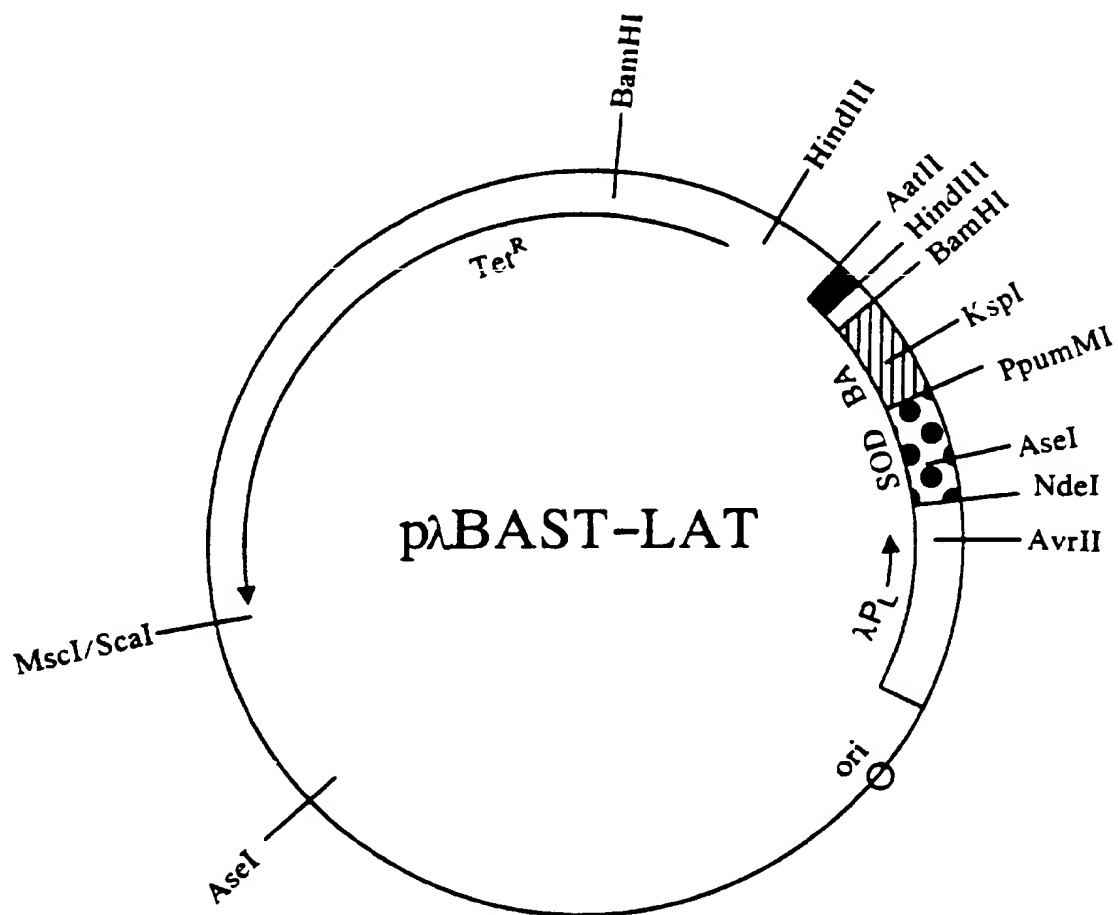
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FIGURE 4



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FIGURE 5



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FIGURE 6

1	Met	Ala	Thr	Lys	Ala	Ala	Ser	Val	Leu	Lys	Gly	Asp	Gly	Pro	Val	Gln	16
1	ATG	GCT	ACT	AAA	GCC	GCT	AGC	GTG	CTG	AAG	GGC	GAC	GGC	CCA	GTG	CAG	48
17	Gly	Ile	Ile	Asn	Phe	Glu	Gln	Lys	Glu	Ser	Asn	Gly	Pro	Val	Lys	Val	32
49	GGC	ATC	ATC	AAT	TTC	GAG	CAG	AAG	GAA	AGT	AAT	GGA	CCA	GTG	AAG	GTG	96
33	Trp	Gly	Ser	Ile	Lys	Gly	Leu	Thr	Glu	Gly	Leu	His	Gly	Phe	His	Val	48
97	TGG	GGA	AGC	ATT	AAA	GGA	CTG	ACT	GAA	GGC	CTG	CAT	GGA	TTC	CAT	ATT	144
49	His	Glu	Phe	Gly	Asp	Asn	Thr	Ala	Gly	Ser	Thr	Ser	Ala	Gly	Pro	Arg	64
145	CAT	GAG	TTT	GGA	GAT	AAT	ACA	GCA	GGC	AGT	ACT	AGT	GCA	GGT	CCT	CGT	192
65	Phe	Val	Asn	Gln	His	Leu	Cys	Gly	Ser	His	Leu	Val	Glu	Ala	Leu	Tyr	80
193	TTT	GTC	AAC	CAG	CAC	CTG	TGT	GGT	TCT	CAC	CTA	ATT	GAA	GCA	CTG	TAC	240
81	Leu	Val	Cys	Gly	Glu	Arg	Gly	Phe	Phe	Tyr	Thr	Pro	Lys	Thr	Lys	Arg	96
241	CTG	GTA	TGT	GGC	GAA	CGT	GGT	TTC	TTC	TAC	ACT	CCT	AAA	ACA	AAG	CGC	288
97	Gly	Ile	Val	Glu	Gln	Cys	Cys	Thr	Ser	Ile	Cys	Ser	Leu	Tyr	Gln	Leu	112
289	GGC	ATC	GTT	GAA	CAG	TGC	TGT	ACC	TCT	ATC	TGT	TCC	CTG	TAC	CAA	CTG	336
113	Glu	Asn	Tyr	Cys	Asn	***											
337	GAG	AAC	TAC	TGC	AAT	TAA											

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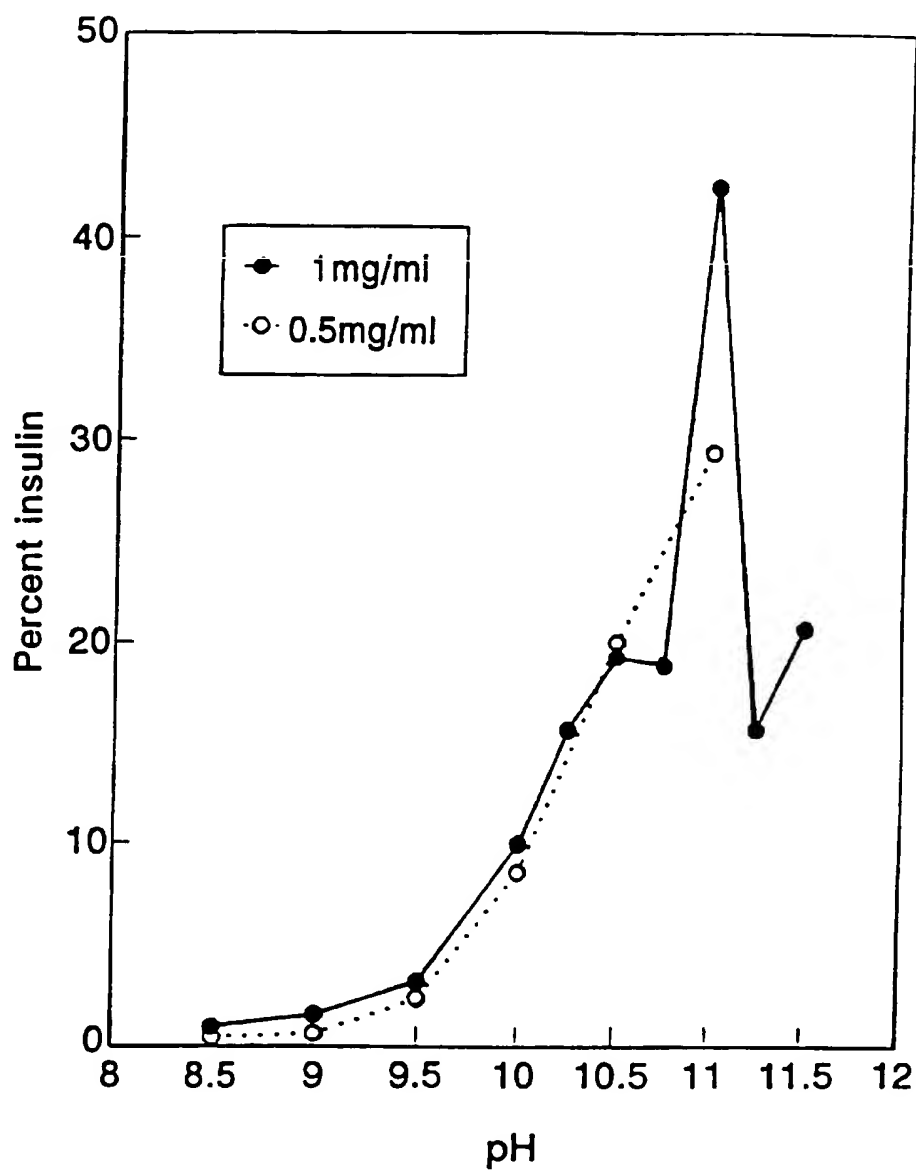
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FIGURE 7

1	Met	Ala	Thr	Lys	Ala	Val	Ser	Val	Leu	Lys	Gly	Asp	Gly	Pro	Val	Gln	16
1	ATG	GCT	ACT	AAA	GCT	GTT	TCT	GTT	TTA	AAA	GGT	GAT	GGT	CCA	GTT	CAA	48
17	Gly	Ile	Ile	Asn	Phe	Glu	Gln	Lys	Glu	Ser	Asn	Gly	Pro	Val	Lys	Val	32
49	GGA	ATT	ATT	AAT	TTT	GAA	CAA	AAA	GAA	AGT	AAT	GGA	CCA	GTT	AAA	GTA	96
33	Trp	Gly	Ser	Ile	Lys	Gly	Leu	Thr	Glu	Gly	Leu	His	Gly	Phe	His	Val	48
97	TGG	GGA	AGT	ATT	AAA	GGA	CTT	ACT	GAA	GGC	CTG	CAT	GGA	TTC	CAT	GTT	144
49	His	Glu	Phe	Gly	Asp	Asn	Thr	Ala	Gly	Ser	Thr	Ser	Ala	Gly	Pro	Arg	64
145	CAT	GAG	TTT	GGA	GAT	AAT	ACA	GCA	GCA	AGT	ACT	AGT	GCA	GGT	CCT	CGT	192
65	Phe	Val	Asn	Gln	His	Leu	Cys	Gly	Ser	His	Leu	Val	Glu	Ala	Leu	Tyr	80
193	TTT	GTC	AAC	CAG	CAC	CAC	CTG	GGT	TCT	CAC	CTG	GTT	GAA	GCA	CTG	TAC	240
81	Leu	Val	Cys	Gly	Glu	Arg	Gly	Phe	Phe	Tyr	Thr	Pro	Lys	Thr	Arg	Gly	96
241	CTG	GTA	TGT	GGC	GAA	CGT	GGT	TTC	TTC	TAC	ACT	CCT	AAA	ACC	CGC	GGC	288
97	Ile	Val	Glu	Gln	Cys	Cys	Thr	Ser	Ile	Cys	Ser	Leu	Tyr	Gln	Leu	Glu	112
289	ATC	GTT	GAA	CAG	TGC	TGT	ACC	TCT	ATC	TGT	TCC	CTG	TAC	CAA	CTG	GAG	336
113	Asn	Tyr	Cys	Asn	***												
337	AAC	TAC	TGC	AAT	TAA												

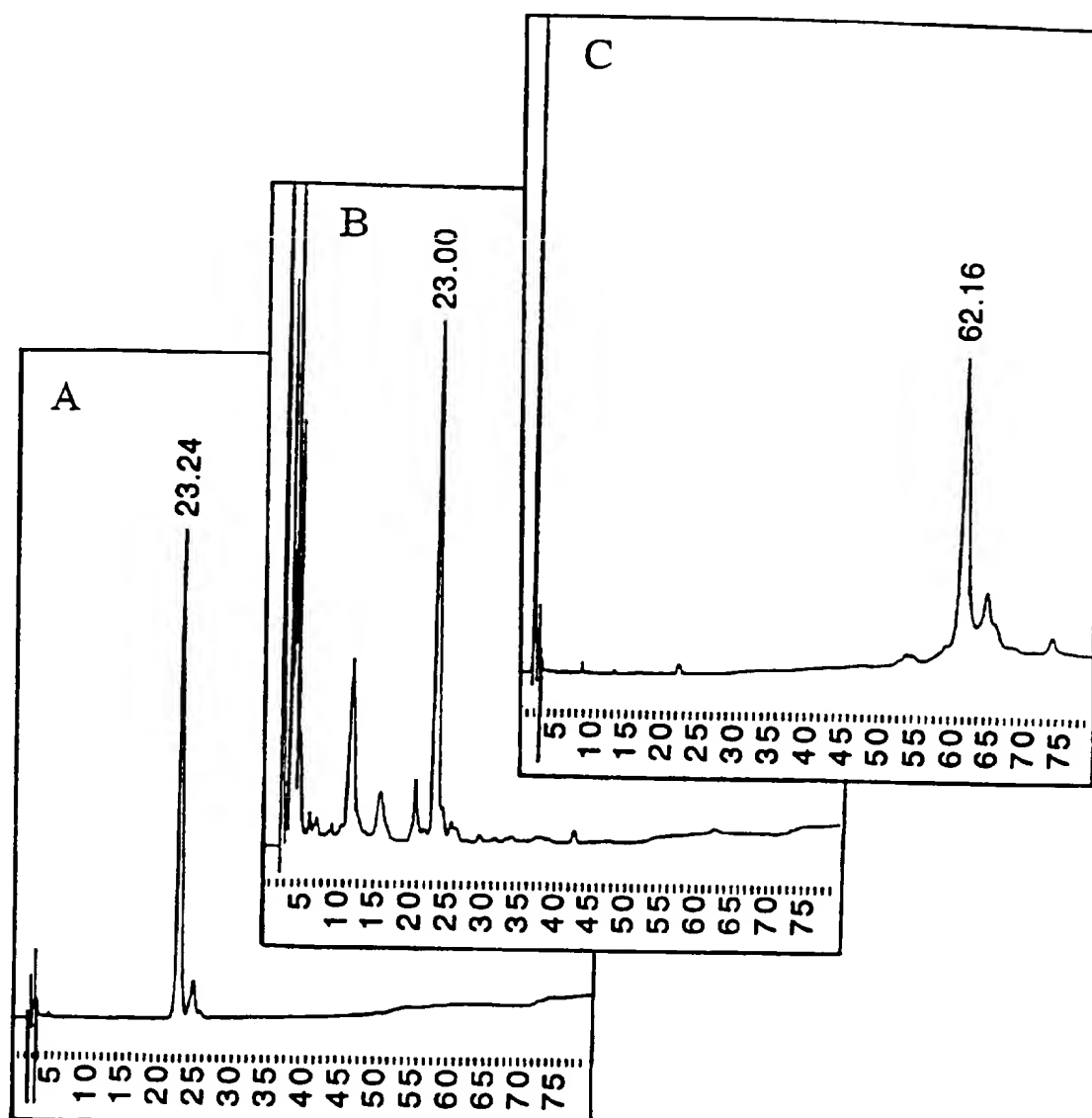
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FIGURE 8



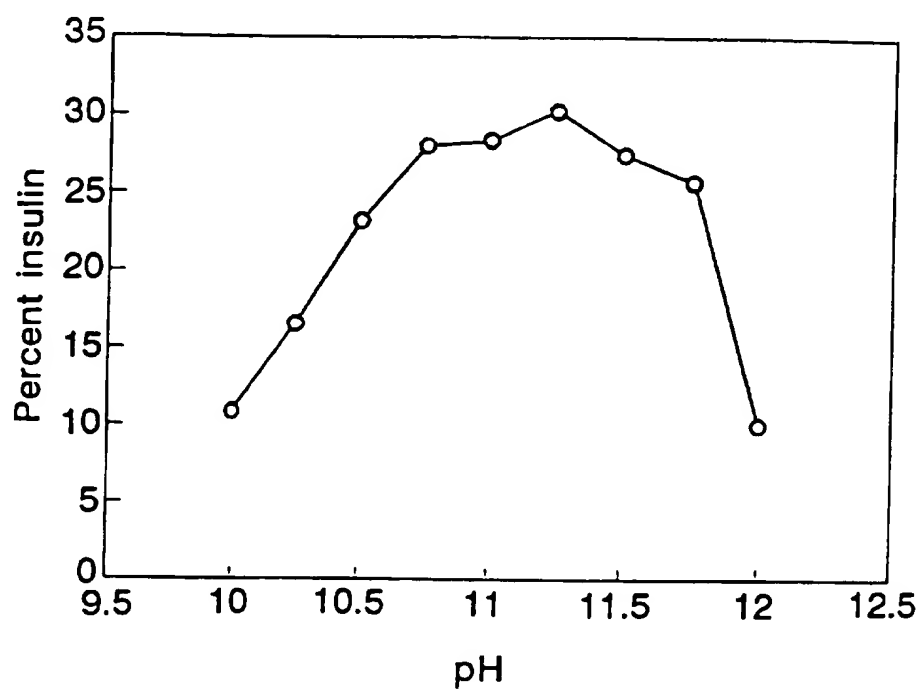
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FIGURE 9



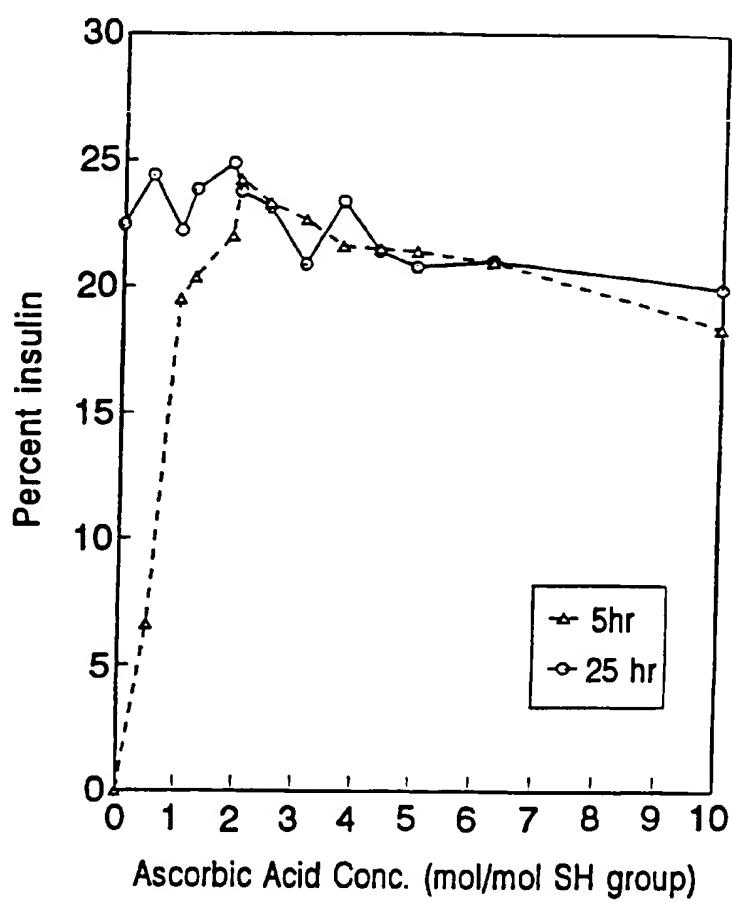
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FIGURE 10



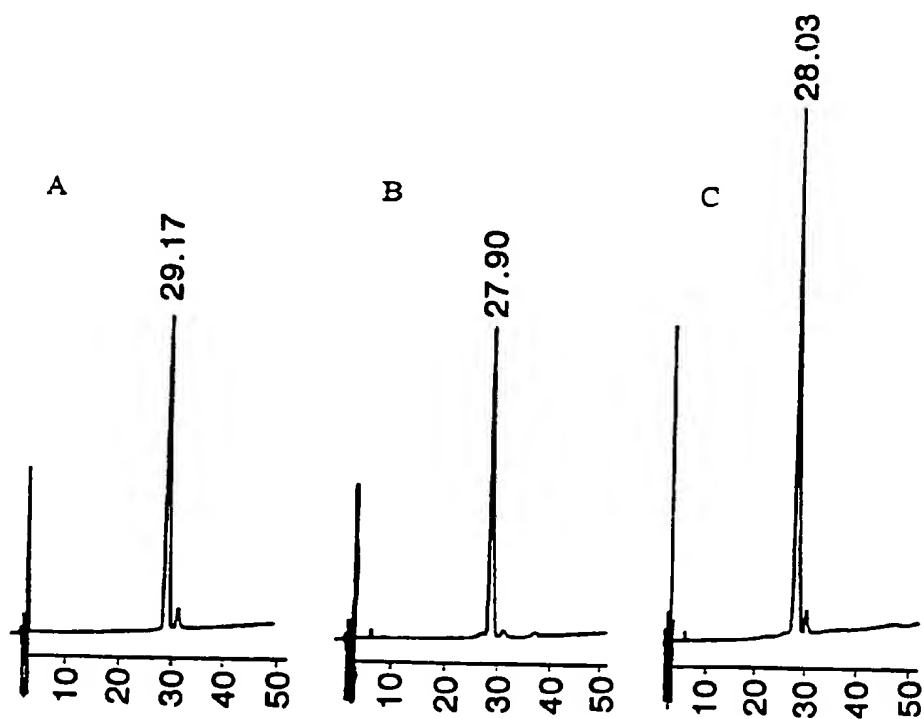
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FIGURE 11



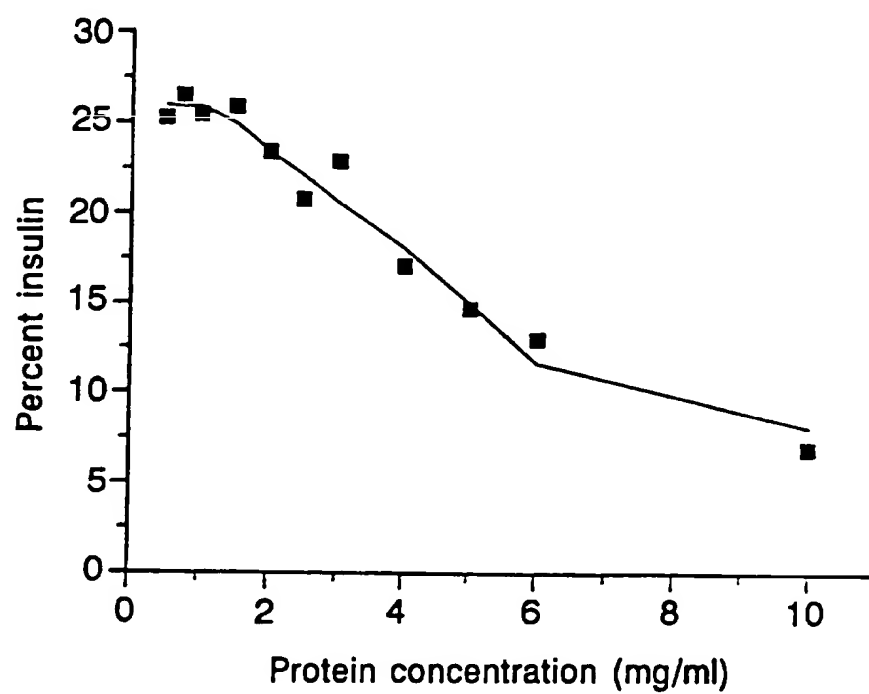
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FIGURE 12



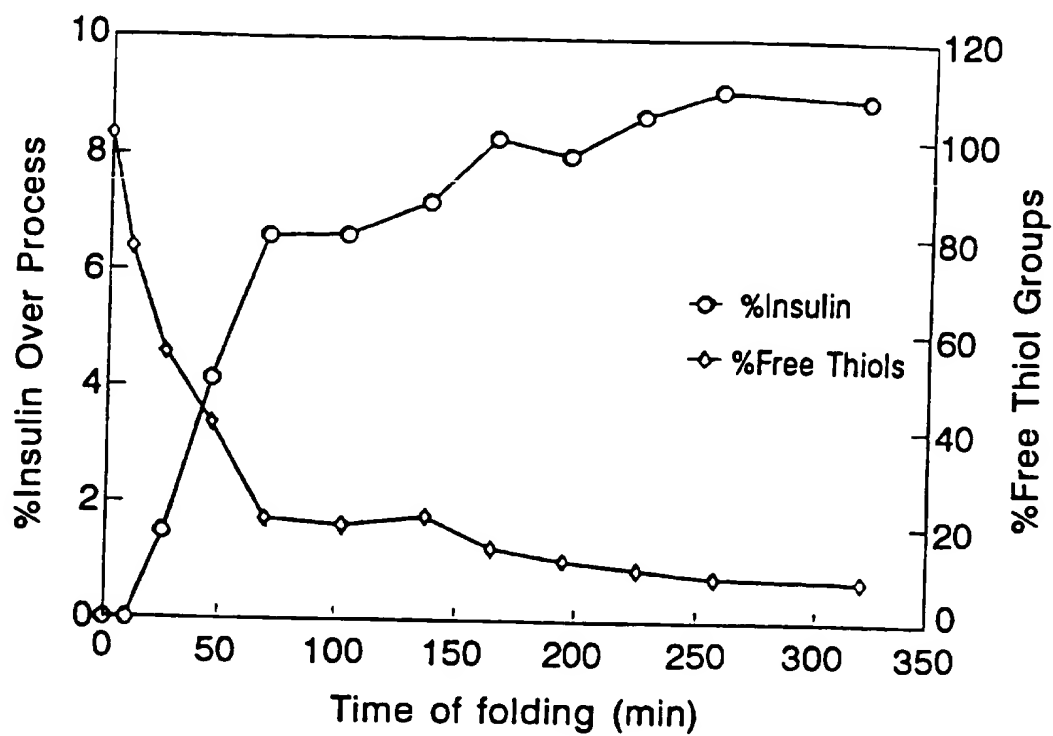
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FIGURE 13



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FIGURE 14



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/13268

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : A61K 38/28; C12N 15/17

US CL : Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/69.4, 69.7, 240.2, 252.33, 255.1, 320.1; 530/303,304,305, 402, 412

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS and DIALOG (files 5, 155, 351, 357, 358) search terms: insulin, proinsulin, ascorbic acid, ascorbate, cysteine, disulfide, folding, refolding, E.coli

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Biochemical and Biophysical Research Communications, Volume 145, No. 1, issued 29 May 1987, H. Inoue et al, "Interchange Reaction of Disulfides and Denaturation of Oxytocin by Copper(II)/Ascorbic Acid/O2 System", pages 596-603, especially pages 600-602.	1-25
X	US, A, 5,342,921 (COUSENS ET AL) 30 August 1994, columns 7-12 and column 16, lines 15-17.	1-2, 9
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Y		3-6, 10-25

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

03 APRIL 1995

Date of mailing of the international search report

12 APR 1995 (12.04.95)

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/13268

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,227,293 (STENGELIN ET AL) 13 July 1993, column 11 through column 13, lines 40, and column 25-26.	1-3, 7-9, 16-17, 19-20, 23 ----- 4-6, 10-15, 18, 21-22, 24-25

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/13268

A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

435/69.4, 69.7, 240.2, 252.33, 255.1, 320.1; 530/303,304,305, 402, 412